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Stephen A.Y. Omule

Province of British Columbia
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August, 1984

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ABSTRACT

This report presents results and conclusions after 28 years' observation of a spacing and thinning study in a Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) plantation on a medium to good site near Lake Cowichan, British Columbia. The study consists of 17 unreplicated plots ranging in final nominal density from 3000 to 125 stems/ha. The plots have been measured nine times at an interval of approximately three years. Stand average and per-hectare values have been calculated by plot and age for all trees and for selected (crop) trees. Analyses indicate that for the ranges investigated, stand quadratic mean diameter (QMD), arithmetic average height (AAH), and growth in QMD and AAH increase with a decrease in density (stems per hectare). Mortality, stand basal area, total volume and growth in stand basal area, and total volume decrease with a decrease in density. Except for extremes of density, stand merchantable volume of all trees and of crop trees are not affected by density. Prolonged early suppression appeared to reduce the ability of a stand to respond to subsequent thinning in terms of basal area and total volume. Heavier thinnings seemed to assure a positive response to thinning in terms of stand basal area, total volume, and QMD. It may be premature to recommend stand management regimes based on this study alone, given that the researcher's confidence in the results is limited by site variations and lack of replication. However, this field study is ongoing and will continue to provide information on the relationship between levels of growing stock and management objectives.

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INTRODUCTION

The Correlated Curve Trend (CCT) studies were devised in South Africa by O'Connor (1935). Essentially these were spacing and thinning experiments, established so that ultimately sets of real-growth series for specific sites and species could be constructed. Examples of design and application of CCT studies are available in Craib (1947), Marsh (1957), O'Connor (1960), Burgers (1968, 1971, 1972, 1976), van Laar (1978, 1982, 1983) and Bredenkamp (1984).

The first CCT experiment to be established in B.C. was Experimental Project (E.P.) 418. The project was established in the summer of 1952 in a 13-year-old Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) plantation on Vancouver Island. (Two similar projects have been established since then: E.P.'s 469 and 554.) This report presents the results and conclusions to date, after 28 years of observation (1952-1980) in the E.P. 418 study area.

METHODS

Study Area

The experimental area is located near Lake Cowichan (latitude 48° 50' N; longitude 124° 02' W) on Vancouver Island. The area was logged in 1933/34, slashburned in 1935, and planted in the spring of 1941 with 2+0 Douglas-fir seedlings at a spacing of approximately 1.8 X 1.8 m. Site index varies between 24 and 37 m at 50 years total age (Warrack 1959).

The plots are situated on a gravelly sandy bench at an elevation of about 200 m above sea level. The surface of the bench is very gently undulated with a general slope of 0-15% in the north and east.

This area is within the CWHa2 variant[1] (East Vancouver Island Drier Maritime Coastal Western Hemlock). The soil profile is Orthic Humo-Ferric Podzol (Canadian Soil Survey Committee 1978); the humus layer is Orthihemimor (Klinka et al. 1981); and the soil parent material is of morainal-glacial origin in most of the study area, though in some parts it is fluvial.

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[1] K. Klinka, K., F.C. Nuszdorfer, and L. Skoda. 1979. Biogeoclimatic units of the Central and Southern Vancouver Island. B.C. Min. For. Report, Victoria, B.C.

Understory vegetation is dominated by salal (Gaultheria shallon Pursh.), bracken fern (Pteridium aquilinum (L.) Kuhn.), sword fern (Polystichum munitum (Kaulf.) Presl.), and bryophytes.

The annual precipitation in the area is about 2123 mm and the daily temperatures average 9.1°C (with a minimum of -1.5°C and a maximum of 24.1°C).

Experimental Design

The experimental design is based on the concept of the CCT designs devised by O'Connor (1935) for thinning research in South Africa. The experiment consists of 17 plots: eight (plots 1-8) constitute the spacing plots representing nominal densities 3000, 1500, 1000, 750, 500, 375, 250, and 125 stems/ha, respectively; and the remaining nine (plots 9-17) constitute the thinning plots, representing different degrees of suppression and/or different degrees of thinning (Table 1).

TABLE 1. Plot thinning schedules

Series and plot	Year Age*	1941 (2)	1952 (13)	1956 (17)	1961 (22)	1965 (26)	1968 (29)	1973 (34)	1976 (37)	1980 (41)	?	Post-thinning density	Remarks
		Nominal trees per hectare											
A	1	3000										3000	Initial spacing plots. Gradual thinning according to interval determined by the rate of growth of the thinned plots compared with a similar number of trees in the previous unthinned plot
	2	3000	1500									1500	
	3	3000	1500	1000								1000	
	4	3000	1500	1000	750							750	
	5	3000	1500	1000	750		500					500	
	6	3000	1500	1000	750		500		375			375	
	7	3000	1500	1000	750		500		375	250		250	
	8	3000	1500	1000	750		500		375	250	125	125	
B	9	3000				2000		1000		500	250	250	Thinning plots: Series mathematically coordinated; several thinning entries
	10	3000			2000	1000		500		250		250	
	11	3000		2000	1000	500		250				250	
	12	3000	2000	1000	500	250						250	
C	13	3000					1000					1000	Thinning plots: Same degree of suppression with different degrees of release (thinning)
	14	3000					500					500	
D	15	3000					500					500	Thinning plots: Different degrees of suppression with the same degree of release (thinning)
	16	3000	1000				500					500	
E	17	3000	2000	1000	500	250						250	Similar to plot 12

*Ages from seed (in years).

Plots 1 to 8 were established in a 13-year-old plantation that had an initial density of approximately 3000 stems/ha. Gradual thinning in advance of mutual competition reduced these plots to their final respective densities. To ensure that competition did not occur prior to stem reduction in plots 1 to 8, the following system (after O'Connor, 1935) was used to determine the appropriate time of thinning: at establishment, plots 2 to 8 were thinned from 3000 to 1500 stems/ha and plot 1 remained at 3000 stems/ha. The arithmetic mean diameter at breast height (dbh) of trees in plots 2 to 8 (d_t) was determined and 1500 trees/ha in plot 1 were subjectively selected to give the same mean dbh (d_c) as that of plots 2 to 8. When d_c fell below d_t by 0.254 cm, competition was then said to have commenced in plot 1, whereupon plots 3 to 8 were thinned to 1000 stems/ha and plot 2 was left at 1500 stems/ha. In a similar manner the relative growth of 1000 trees in plots 2 and 3 determined the time to thin plots 4 through 8 to 750 stems/ha. The same system was used to thin plots 5 through 8 to 500 stems/ha, plots 6 through 8 to 375 stems/ha, plots 7 and 8 to 250 stems/ha, and plot 8 to 125 stems/ha. The actual ages at which the thinnings took place are given in Table 1.

Plots 9 to 17, established in the same plantation, were thinned from an initial density of 3000 stems/ha to various final densities at different ages, usually after the onset of competition. Table 1 gives these thinning schedules.

The plots are rectangular (with most being square), their areas varying from 0.091 to 0.303 ha. The plot areas and number of trees before and after the thinning at establishment (age 13) are given in Table 2. At establishment, a "free thinning" was used to balance the gaps and clusters of trees within a plot. Subsequent thinnings removed trees from a range of diameter classes. During each thinning an attempt was made to achieve a uniform nominal spacing of residual trees within a plot, and larger and healthier trees were favoured. The ratio of average diameter of thinned trees to average diameter of trees before thinning ranged from about 0.7 to 1.0. All thinned trees were left on site. The plots had a 15-m wide buffer zone and a distance of at least 30 m maintained between adjacent plots.

TABLE 2. Plot area and number of trees at establishment

Series and plot		Area (ha)	Number of trees/plot Before thinning	Thinned	After thinning	Remaining number of trees/ha
A	1	0.0911	270	--	270	2964
	2	0.0911	239	104	135	1482
	3	0.0911	205	70	135	1482
	4	0.0911	322	187	137	1504
	5	0.0911	288	153	135	1482
	6	0.1214	299	127	172	1417
	7	0.2023*	470	178	292	1443
	8	0.3035	677	227	450	1483
B	9	0.0911	365	95	270	2964
	10	0.0911	350	80	272	2964
	11	0.0911	384	114	270	2964
	12	0.0911	242	62	180	1976
C	13	0.0911	272	2	270	2964
	14	0.0911	280	10	275	3018
D	15	0.0911	265	—	265	2909
	16	0.0911	248	164	84	922
E	17	0.0911	306	126	180	1976

*As a result of root rot, the area of plot 7 was reduced to 0.1427 ha in 1968.

Measurements and Summaries

In 1953, one year after the initial thinning, all trees within each plot were serially numbered and tagged. The condition of all the trees; the diameter at breast height of those trees with a measurable diameter (dbh, outside bark at 1.37 m); and the total height of a subsample of trees (at least 10) within each plot were recorded on the following dates: September 1953, April 1956, June 1959, September 1961, July 1965, August 1968, September 1973, October 1976, and June 1980. In all the measurements, dbh was taken at approximately the same height (1.37 m) and total height was taken on the same subsample of trees in each plot. If a "height tree" was dead or defective (e.g. with a broken or dead top), a replacement tree of approximately the same dbh was chosen. Sometimes additional trees were measured for height.

Crop trees were selected and marked in 1962 (at age 23 years). These numbered 14 to 56 trees per plot (depending on plot area) -- those of largest diameter, free of defect, and with a spacing consistent with that of the plot final nominal spacing. Some of the selected trees were subsequently lost to thinning or mortality (largely from root rot). The lost crop trees were not replaced.

Measurements prior to 1976 were taken in imperial units and subsequently converted to metric units.

Unmeasured tree heights were estimated from appropriate height-diameter equations fitted separately for each measurement period for each plot. The height-diameter model suggested by Schreuder and Hafley (1977) was used, since there was a sufficiently large number of heights. The total volume of each tree was estimated from the following (natural stand) tree volume equations:

1) Trees greater than 10 m total height[2]:

$$\ln V = -9.872837 + 1.869321 \ln D + 0.967596 \ln H$$

SEE = 0.0877 m^3; R^2 = 0.996, N = 630

where

V = total volume in cubic metres (whole stem, inside bark)

D = dbh outside bark in centimetres

H = total height in metres

ln = natural logarithm.

2) Trees less than or equal to 10 m total height (Kovats 1977):

$$\ln V = -3.33875 + 1.70435 \ln d + 1.38551 \ln H + 2.03499 (h/H)$$

SEE = 10.29%, R^2 = 0.996, N = 100

---

[2] This equation was developed by G. Godfrey (Research Branch; personal communication, 1983) from sample trees collated from coastal British Columbia. The equation is restricted to coastal Douglas-fir up to 100 years old and dbh greater than or equal to 5 cm; it is more accurate (especially for smaller trees) than the equations in British Columbia Forest Service (BCFS) (1976).

where

V = total volume in cubic centimetres (whole stem, inside bark)

d = diameter outside bark in centimetres at height (h) in centimetres

h = distance in centimetres from point of germination to the point of diameter (d) measurement

H = total height in centimetres.

Merchantable volume, defined as stem volume inside bark excluding a 30-cm stump and a 10-cm diameter inside bark top, was calculated using the following equation[3] (BCFS 1976):

Equation	Diameter range (cm)
$MV = 0.97V$	≥ 42.5
$= 0.96V$	32.5 - 42.4
$= V[0.9563(1-e^{-0.37770(D-9.004)})^{0.660}]$	9.1 - 32.4
$= 0$	≤ 9.0

where

MV = merchantable volume in cubic metres

V = total volume in cubic metres

D = dbh outside bark in centimetres.

The individual tree measurements were edited and summarized into stand average and per-hectare values per plot at each measurement period, for thinned (cut) trees, mortality (dead) trees, standing (living) trees, and gross (all = thinning + mortality + standing) trees. Trees with a zero dbh or less than 1.37 m tall were excluded from the summaries. Details of data compilation and

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[3] The part of the equation for D < 32.5 was developed by G. Godfrey (Research Branch; personal communication, 1983) who fitted an equation to the tabulated values of merchantable volume factors in BCFS (1976), facilitating more precise interpolation of the BCFS (1976) tables for this range of diameters.

summaries (plot statistics and stand and stock tables) for all trees and for crop trees in each plot are given in the E.P. 418 progress report.[4]

ANALYSES

Site index (at total age 50 years) was estimated for each plot (Table 3). Top height was calculated as the arithmetic mean total height (measured or estimated from a height-diameter curve) of the 100 trees/ha of largest diameter in each plot at age 41 years. The calculated top height was then used to enter the site index curves derived from Warrack (1959).[5] The method of analysis of the CCT data suggested by O'Connor (1935) was inappropriate because of the wide range of sites (Table 3). Furthermore, conventional methods of treatment comparison, such as analysis of covariance, could not be applied because the plots were not replicated. However, it was possible to compare yield and increment statistics within the various spacing and thinning regimes. The analyses were done separately for the spacing plots (plots 1-8) and the thinning plots (plots 9-17).

Spacing

Analyses were performed on data from plots 1 to 6 only, because plot 7 was recently thinned and plot 8 has not been reduced to its final nominal density. The analyses were done separately for all trees and crop trees.

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[4] S.A.Y. Omule. 1984. A progress report on E.P. 418: A correlated curve trend spacing and thinning experiment in a pure, even-aged plantation of Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] on Vancouver Island. B.C. Min. of For. Res. Br. Rep. File: E.P. 418, Victoria, B.C. 280 p.

[5] The hand-fitted curves of Warrack (1959) were refitted by least-squares (K. Mitchell and I. Cameron; personal communication, 1983) to give site index curves of the form:

$$H = b1S^{b2}(1-e^{b3A})^{b4S^{b5}}$$

where, H = top height in metres, A = total age in years, S = site index (at total age 50 years), b1= 1.722822, b2 = 0.949754, b3 = -0.0378781, b4 = 3.56148, and b5 = -0.133798.

TABLE 3. Estimated site indices of the plots

Plot	Top height at age 41 yr (m)	Site index at total age 50 yr (m)
1	25.3	29.8
2	29.2	34.3
3	23.0	27.2
4	24.3	28.7
5	27.0	31.8
6	23.5	27.7
7	22.5	26.6
8	25.3	29.8
9	26.0	30.6
10	30.5	35.8
11	30.6	35.9
12	30.3	35.6
13	27.0	31.8
14	28.0	32.9
15	27.1	31.9
16	25.5	30.0
17	28.5	33.5

Average and per-hectare stand values (quadratic mean diameter, average height, basal area per hectare, total volume per hectare, and merchantable volume per hectare) were compared among the six plots to detect differences in yield and increment among the various spacings. Each yield and increment parameter (for all trees and crop trees) was related to top height rather than age because of the variation in site index.

Tests for bias and precision led to the selection of the following model:

$$\ln Y = a + b \ln X$$

where

Y = stand average or per-hectare value of standing trees

X = top height of standing trees

a, b = regression coefficients

ln = natural logarithm.

For each Y (stand value), the resulting set of six curves (one per plot) was tested for parallelism and coincidence with a sequential analysis of variance (Kozak 1970).

In addition, stand average and per-hectare values at top height 23 m were estimated by interpolation within the data summary tables. Top height 23 m was chosen as a base for comparison because it was the highest common top height among the plots.

Net and gross periodic increments in basal area per hectare, and total and merchantable volumes per hectare of plots 1 to 6 were calculated for the 1953-1980 growth period. Percentage growth rates were calculated in terms of compound interest (Husch et al. 1972, p. 304).

Mortality was assessed by relating the number of trees and average spacing to top height through the Hart-Becking spacing index S% (Loetsch et al. 1973, p. 227). It is defined as $S\% = 10\,000/(H_t \sqrt{SPH})$, where H_t = top height in metres and SPH = stems per hectare. In addition, cumulative mortality was expressed as a percentage of the nominal density at ages 34, 37, and 41 for each plot.

Thinning

Analyses were limited to plots 11 through 17 which had not been thinned recently (unlike plots 9 and 10). Some plots were thinned (to varying degrees) in advance of competition and others after the onset of competition. The effects of the intensity and timing of single entry thinning on average and per-hectare values were studied by comparing the thinned plots with the unthinned plots of the same final nominal density. Plots 13 (light thinning) and 14 (heavy thinning) were compared with plots 3 and 5, respectively, to determine the effect of thinning intensity. Plots 14 and 15 (delayed first entry) and 16 (early first entry) were compared to plot 5 to determine the effect of timing of the first thinning entry.

Thinning response for plots 11 to 16 was obtained as follows:

1) The observed values (e.g. basal area per hectare) at top height 23 m in plots 3, 5, and 13 to 16 were obtained by interpolation from the data summaries.
2) For each plot the ratio of the nominal stems per hectare to actual stems per hectare at top height 23 m was calculated.
3) The observed values in (1) were weighted by the corresponding ratios in (2).

4) Response was calculated as the difference between the weighted value of the thinned plot and that of the corresponding unthinned plot, expressed as a percentage of the latter.

Net and gross periodic increments in basal area per hectare, and total and merchantable volumes per hectare of plots 11 to 17 were calculated for the 1953-1980 growth period.

RESULTS

Spacing

Stand Diameter

The regressions of quadratic mean diameter (QMD) on top height for plots 1 to 6 showed that plots 2 and 3 were similar, as were plots 4 and 5. Other comparisons were significantly different (i.e. 1 2 3 4 5 6: $p = 0.05$). The slopes of these regressions increased from 0.996 (plot 1) to 1.261 (plot 6). At top height 23 m, the QMD obtained by interpolation from the data summaries were: 14.4, 19.7, 19.7, 21.5, 21.7, and 24.4 cm for plots 1 to 6, respectively. The stand QMD and QMD growth for all trees increased with a decrease in density (stems per hectare). However, the QMD growth of selected (crop) trees was the same in plots 2 to 5 and different in plots 1 and 6 (i.e. 1 2 3 4 5 6: $p = 0.05$). This means that, for crop trees, QMD and QMD growth were not affected by density, except at the extremes (plots 1 and 6).

Average height

The regressions of arithmetic average height (AAH) on top height for plots 1 to 6 showed that plots 2 and 3 were similar as were 4 and 5. Other comparisons were significantly different (i.e. 1 2 3 4 5 6: $p = 0.05$). The slopes of these regressions increased from 1.12 (plot 1) to 1.31 (plot 6). At top height 23 m, the AAH were: 13.1, 20.0, 18.3, 19.8, 19.9, and 19.7 m for plots 1 to 6, respectively.

The stand AAH and AAH growth for all trees increased with a decrease in density. However, the AAH growth of crop trees was the same in plots 2 to 5

but different in plot 1 or 6. This means that density did not affect AAH and AAH growth of crop trees except at the extremes (plot 1 or 6).

Basal area

The regressions of basal area per hectare on top height for plots 1 to 6 showed that plots 1 and 2 were similar, as were 3 and 4, and 5 and 6 (i.e. 1 2 3 4 5 6: p = 0.05). The slopes of the regressions decreased from 1.76 (plot 1) to 1.50 (plot 6). At top height 23 m, the basal areas were: 35.4, 34.6, 25.0, 26.3, 19.0, and 17.2 m^2/ha for plots 1 to 6, respectively. Wider spacing resulted in lower stand basal area and stand basal area growth. The basal area trends for crop trees were similar in plots 1 and 2, as were 3, 4, and 5. Other comparisons were significantly different (i.e. 1 2 3 4 5 6: p = 0.05).

Net and gross periodic increments were determined for stand basal area in plots 1 to 6 (Table 4). Although it was not possible to make any meaningful statistical comparisons among the plot statistics, it appears that gross production in basal area decreased with a decrease in stand density.

Volume

Results similar to those found for basal area were obtained for tests in regressions of total volume on top height of all trees (i.e. 1 2 3 4 5 6: p = 0.05). The total volumes of all trees at top height 23 m were: 258, 295, 202, 216, 156, and 139 m^3/ha for plots 1 to 6, respectively.

Thus, total volume and volume growth decreased with a decrease in stand density. Crop tree total volumes were also influenced by stand density (i.e. 1 2 3 4 5 6: p = 0.05). The regressions of merchantable volume on top height for all trees or for crop trees (except for plot 6) were identical among the plots. At top height 23 m, the merchantable volumes were: 207, 261, 180, 197, 142, and 130 m^3/ha for plots 1 to 6, respectively. This means that stand density did not affect stand merchantable volume of all trees or crop trees (except at the low final density in plot 6).

Net and gross period increments were determined for stand total and merchantable volume in plots 1 to 6 (Tables 5 and 6). As before, meaningful comparisons among the plot statistics were not possible to make. However, it

appears that gross production in total and merchantable volume decreased with a decrease in stand density.

It is worth noting here that the total volumes were estimates from tree volume tables derived from trees in natural stands. Neither the volume tables nor this experiment consider the effects of spacing and thinning on stem form. Meng (1981, p. 111) states that this "could well yield biased estimates and could ultimately lead to erroneous conclusions".

Mortality

The percent cumulative mortality (M%) and the corresponding Hart-Becking spacing index (S%) are shown for ages 34, 37, and 41 in Table 7. It was apparent that mortality increased with age and decreased with decreasing stand density, although site and various unknown factors might possibly have confounded these effects.

Thinning

The average and per-hectare plot values at top height 23 m are shown for plots 3, 5, and 11 to 17 in Table 8. The response to light thinning (plot 13), to heavy thinning (plot 14), and to thinning following light early suppression (plot 16) and heavy early suppression (plot 15) are shown in Table 9.

TABLE 4. Basal area net and gross periodic increments

	Plot No.																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1953 Basal area (m^2/ha)	3.6	3.3	2.0	2.2	2.4	2.4	2.9	3.3	5.6	8.3	7.6	5.8	4.0	5.5	2.7	1.5	4.5
1980 Basal area (m^2/ha)	40.2	45.0	25.0	29.2	26.1	18.0	14.5	17.4	26.6	22.7	25.8	25.5	39.6	30.4	26.6	25.4	28.1
Basal area thinned (m^2/ha)	0.0	0.0	1.2	3.4	6.8	6.5	12.5	15.0	14.9	36.1	37.9	21.3	8.8	19.1	12.0	6.4	18.6
Net increment*	36.4	41.7	24.2	30.4	30.5	22.1	24.1	29.1	35.9	50.5	56.1	41.0	44.4	44.0	35.9	30.3	42.2
Net p.a.i.** (m^2/ha/year)	1.35	1.54	0.90	1.13	1.13	0.82	0.89	1.08	1.33	1.87	2.08	1.52	1.64	1.63	1.33	1.12	1.56
Net p.a.i.% (%)	9.13	10.16	10.00	10.50	10.18	8.99	8.61	8.83	7.70	7.52	8.19	8.04	9.67	8.48	10.35	11.98	9.06
Mortality (m^2/ha)	5.7	6.3	2.3	0.3	0.0	4.2	3.7	1.5	15.7	4.8	0.4	3.6	8.2	11.0	7.6	0.5	1.8
Gross production (m^2/ha)	45.9	51.3	28.5	32.9	32.9	28.7	30.7	33.9	57.2	63.6	64.1	50.4	58.6	60.5	46.2	32.3	48.5
Gross increment	42.1	48.0	26.5	30.7	30.5	26.3	27.8	30.6	51.6	55.3	56.5	44.8	52.6	55.0	43.5	30.8	44.0
Gross p.a.i.	1.56	1.78	0.98	1.14	1.13	0.97	1.03	1.13	1.91	2.05	2.09	1.65	1.95	2.04	1.61	1.14	1.63
Gross p.a.i.%	9.67	10.69	10.34	10.54	10.18	9.63	9.13	9.01	8.99	7.83	8.22	8.34	10.31	9.29	11.09	12.04	9.06

* Includes ingrowth

** P.a.i. = periodic annual increment

TABLE 5. Total volume net and gross periodic increments

	Plot No																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1953 Total volume (m^3/ha)	9.8	9.6	5.0	5.8	6.3	6.3	8.0	9.6	16.2	26.6	23.4	17.4	10.1	14.2	6.6	3.9	11.7
1980 Total volume (m^3/ha)	324.0	464.1	202.3	247.2	243.0	147.6	117.8	160.6	250.9	242.5	277.9	271.4	385.3	308.4	257.1	238.4	284.6
Total volume thinned (m^3/ha)	0.0	0.0	2.9	11.4	31.7	31.9	75.3	106.1	112.3	278.8	257.1	116.4	55.8	137.0	75.0	41.6	93.0
Net increment*	314.2	454.5	200.2	252.8	268.4	173.2	185.1	257.1	347.0	494.7	511.6	370.4	431.3	431.2	325.5	276.1	385.9
Net p.a.i.** (m^3/ha year)	11.64	16.83	7.41	9.36	9.94	6.41	6.86	9.52	12.85	18.32	18.95	13.72	15.97	15.97	12.06	10.23	13.55
Net p.a.i.% (%)	13.83	15.45	14.75	15.10	15.01	13.21	12.52	13.10	12.21	11.65	12.29	12.18	15.02	13.61	15.62	17.15	13.73
Mortality (m^3/ha)	29.7	47.7	13.8	2.2	0.0	27.7	22.6	10.1	100.7	32.2	2.1	32.9	52.9	74.2	39.6	4.0	15.2
Gross production (m^3/ha)	353.7	511.8	219.0	260.8	274.7	207.2	215.7	276.8	466.9	553.5	537.1	420.7	494.3	519.6	371.7	284.0	392.8
Gross increment	343.9	502.2	214.0	255.0	268.4	200.9	207.7	267.2	450.7	526.9	513.7	403.3	484.2	505.4	365.1	280.1	381.1
Gross p.a.i. (m^3/ha year)	12.74	18.6	7.93	9.4	9.94	7.44	7.69	9.90	16.69	19.51	19.03	14.93	17.93	18.72	13.52	10.37	14.11
Gross p.a.i.%	14.20	15.87	15.03	15.14	15.01	13.81	12.98	13.26	13.26	11.90	12.31	12.52	15.49	14.26	16.10	17.21	13.90

* Includes ingrowth
** P.a.i. = periodic annual increment

TABLE 6. Merchantable volume net and gross periodic increments

	Plot No																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1953 Merch volume*(m^3/ha)	0.7	0.1	0.0	0.0	0.0	0.4	0.2	0.8	0.1	1.3	1.6	1.8	0.3	0.3	0.0	0.0	0.0
1980 Merch volume (m^3/ha)	273.5	430.7	179.6	227.4	228.0	138.5	111.4	153.1	235.8	233.5	268.9	262.6	354.5	293.3	242.7	223.9	275.6
Merch volume thinned (m^3/ha)	0.0	0.0	0.0	2.2	15.8	19.7	57.6	86.5	84.1	211.6	199.4	84.6	27.4	98.2	50.1	287	60.6
Net increment**	272.8	430.6	179.6	229.6	243.8	157.8	168.8	238.8	319.3	446.8	466.7	345.6	381.6	391.2	292.8	252.6	336.2
Net p.a.i***(m^3/ha year)	10.10	15.96	6.65	8.50	9.03	5.84	6.25	8.54	11.84	16.55	17.28	12.80	14.13	14.49	10.84	9.36	12.45
Net p.a.i.% (%)	24.74	36.33	—	—	—	24.79	28.35	23.51	34.84	24.16	23.41	21.52	30.31	30.43	—	—	—
Mortality (m^3/ha)	13.9	33.2	9.5	1.1	0.0	22.4	17.7	7.7	64.9	20.7	1.1	30.5	25.4	34.8	15.5	3.4	14.3
Gross production (m^3/ha)	287.4	463.9	189.1	230.7	243.8	180.6	186.7	247.3	384.8	468.8	469.4	377.9	407.3	426.3	308.3	256.00	350.5
Gross increment	286.7	463.8	189.1	230.7	243.8	180.2	186.5	246.5	384.7	467.5	467.8	376.1	407.0	426.0	308.3	256.0	350.5
Gross p.a.i. (m^3/ha year)	10.62	17.18	7.00	8.54	9.03	6.67	6.91	9.12	14.25	17.31	17.33	13.93	15.07	15.78	11.42	9.48	12.98

* Merch. volume = total volume inside bark less a 30-cm stump and 10-cm diameter inside bark top
** Includes ingrowth
*** P.a.i. = periodic annual increment

TABLE 7. Cumulative mortality (M%) and spacing index (S%)

Plot	Nominal density (stems/ha)	Period (age in years) 29-34		34-37		37-41	
		M%	S%	M%	S%	M%	S%
1	3000	22.7	9.6	27.1	9.0	31.8	8.8
2	1500	24.1	12.0	24.8	11.1	31.5	10.8
3	1000	4.4	16.8	12.1	16.0	23.1	15.3
4	750	4.4	17.9	5.9	16.5	5.9	15.3
5	500	0.0	19.4	0.0	17.6	0.0	16.4

TABLE 8. Weighted stand average and per-hectare values at top height 23 m

Value	Plot No.					
	3	5	13	14	15	16
Basal area/ha (m^2/ha)	30.5	18.4	31.0	21.6	20.5	22.3
Total volume/ha (m^3/ha)	245.8	151.3	261.3	187.3	174.9	191.1
Average height (m)	18.3	19.9	20.3	21.7	21.1	21.5
Merch. volume/ha (m^3/ha)	218.2	137.9	231.7	173.6	161.3	177.4
Quadratic mean diameter (cm)	19.7	21.7	19.8	23.3	22.9	23.7

TABLE 9. Responses to thinning at top height 23 m

Thinning treatment	Response (%) at 23 m				
	Basal area/ha	Total volume/ha	Merch. volume/ha	Quadratic mean diameter	Average height
Light thinning (plot 13 compared to plot 3)	2.0	6.3	6.2	0.0	10.9
Heavy thinning (plot 14 compared to plot 5)	17.4	23.8	25.9	7.3	9.0
Heavy early suppression (plot 15 compared to plot 5)	11.4	15.6	17.0	9.2	6.0
Light early suppression (plot 16 compared to plot 5)	21.2	26.3	28.6	5.6	8.0

Heavy thinning (80% in this case) appears to have increased the basal area, and volume response (total and merchantable) at top height 23 m (Table 9). However, some of the response may have been due to chance variation in these unreplicated plots. Light early suppression increased the basal area and volume response to thinning, relative to heavy early suppression and light thinning. Stand arithmetic average height response to thinning did not seem to be influenced by thinning intensity or degree of early suppression. Stand diameter responded to thinning intensity (0.0% and 7.3% for light and heavy thinning, respectively) or degrees of suppression (5.6% and 9.2% for light and heavy suppression, respectively).

The quadratic mean diameter and merchantable volume per hectare were consistently higher in plots 12 and 17 than in plot 11, at ages 37 and 41. This indicated that an early thinning entry resulted in larger stand diameter and more merchantable volume.

Net and periodic increments were determined for plots 9 to 17 for only per-hectare values (Tables 4, 5, and 6), but again no meaningful comparisons could be made among the plot statistics.

DISCUSSION AND CONCLUSIONS

The significant differences in site quality among plots, and their unreplicated nature, tremendously restricted the analysis of the data and interpretation of the results from this experiment. Conventional statistical methods of treatment comparison could not be applied. In the spacing plots, plot comparisons were based on the method of parallelism and coincidence tests of regression lines, in which top height was the concomitant variable. The assumption was that top height accounted fully for the variation in plots as a result of differences in site. Another assumption was that top height was fixed (a basic requirement in the ordinary least-squares regression used). In the thinning plots, the plots were compared to the corresponding spacing plots of the same nominal density. It was assumed that the spacing plots were thinned early in advance of competition. However, the rule used to decide when competition actually set in (after O'Connor 1935) was rather arbitrary,

and it is probable that some of the spacing plots were thinned after the onset of competition. Furthermore, the distribution and quality of trees expected from plots in which densities are established at the appropriate initial spacings may be different from those observed in the spacing plots. (It was not possible to determine to what extent selection by thinning for microsite and genetic factors had improved yields in the plots.)

The range of treatments and conditions in this study indicated that:

1) diameter and diameter increment increased with a decrease in density, as did height and height increment. However, corresponding crop-tree parameters were not affected except at the extreme density of 3000 stems/ha. Similar results were reported by Reukema (1979) for all trees on poor sites, though, he found that crop trees responded in parallel with all trees. This difference may have resulted from the method of crop-tree selection, the number of crop trees selected, or site differences in the study areas.
2) wider spacing resulted in lower basal area, total volume, and increment for the entire stand. Crop trees were little affected. Reukema (1979, p. 11), however, reported that, on a poor site with a spacing range of 1.2-3 m, "Basal area of live trees tends to increase as spacing increases". This difference may have resulted from differences in spacing levels and site in the study areas.
3) merchantable volume was not affected by density. However, because the volume in the denser plots is concentrated in smaller diameter classes, premiums for large dimensions may increase the value of wide spacing.
4) mortality increased over time, and with a decrease in density. Most mortality was largely due to inter-tree competition, although snow damage (at age 23) and root rot were also important.
5) heavy early suppression reduced the ability of a stand to respond to subsequent thinning, and produced smaller trees with less merchantable volume (compared to light early suppression). This result agrees with that of Tappeiner et al. (1982) who recommended early precommercial thinning to maximize volume growth.

6) heavy thinning assured a positive response to thinning. Hall et al. (1980) report similar results for average height and diameter growth on a poor site; Harrington and Reukema (1983) also report similar results for height, diameter, basal area, and volume growth on a poor site.

It may be premature to recommend stand management regimes based on this study alone, given that the researcher's confidence in the results is limited by site variations and lack of replication. However, analysis of the data from the other CCT studies (E.P.'s 469 and 554) will help verify and expand the conclusions from this study. This field study is ongoing and will continue to provide information on the relationship between levels of growing stock and management objectives.

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